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SWITCHES AND TURNOUTS

HOWARD CHAPIN IVES

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Switches and Turnouts

By HOWARD CHAPIN IVES

Assistant Professor of Railroad Engineering

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PREFACE.

The three articles under this cover are reprints from the *Journal of the Worcester Polytechnic Institute* for March, May and July, 1907. Attention is called to the following points:— first, the descriptions of the different forms of switches and their effect on the lead; second, the statement of practical conclusions at various places; and third, the design of the slip switch, the mathematics of which have not been found elsewhere by the writer.

The reader and student are advised to get a clear understanding of the first part before proceeding further because it is believed that a large part of the difficulty experienced by students of this subject is due to a poor understanding of the essentials of the different forms of switches.

June 15, 1907. H. C. I.

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SWITCHES AND TURNOUTS.*

By Professor Howard Chapin Ives.

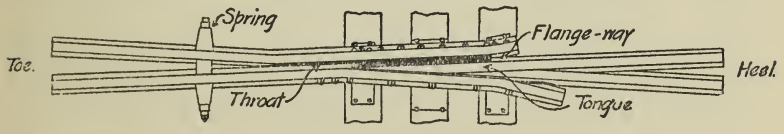
A turnout is a curved track leading from another track, and is composed of five principal parts as follows:—

a. The switch rails by which the wheels of the train are diverted from the main track. b. The frog which is at the point where the outer rail of the turnout crosses one rail of the main track, and which allows the flanges of the wheels to pass this rail. c. The lead rails which connect the switch rails and the frog. d. The rails beyond the frog point. e. The guard rails.

These different parts will be considered in order except that the frog will be taken up first.

THE FROG.

The figure below gives the different parts of a spring frog. In the rigid frog the wing rails are both fastened securely to the main part of the frog, sufficient clearance being left. The spring frog is used where the bulk of the traffic is on the main track, and the wing rail is pushed back by the wheels of the train passing through the turnout.



The Spring Frog.

The position of the frog in the turnout is shown in the sketch of the stub switch given later.

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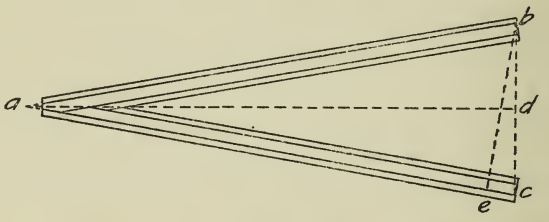
The frog angle is the angle between the sides of the triangular part of the frog. The frog number, N, is found in three different ways as follows: First, by dividing the length of the frog by the distance gage to gage at its heel, or in the figure, $N = \frac{a\,d}{b\,c}$, whence since $\frac{a\,d}{b\,d} = \cot \frac{1}{2}F$, we have,

$$2N = \cot \tfrac{1}{2}F. \qquad (1)$$

Second, by dividing the distance along the gage line from the switch point to the heel of the frog by the distance gage



to gage at the heel or in the figure, $N = \frac{ab}{bc}$, whence since $\frac{ab}{bd} = \text{cosec } \frac{1}{2}F$, we have $2N = \text{cosec} \frac{1}{2}F$. (2)

Third, by dividing the distance along the gage line by the perpendicular distance *be*, that is $N = \frac{ab}{be}$.

The first method is given in nearly all the railroad engineers' field books. The second method is used by many frog and switch manufacturers, and the third method is very convenient in the derivation of certain approximate formulas. The particular advantage of the second method is that the measurement is made along a certain definite line.

The angle for a number four frog by the first method is 14° 15′ and by the second method 14° 22′. The difference in the distances between the sides of a number four frog in a length of five feet, would be about one eighth of an inch,

and would of course be much less with a greater frog number. The first method will be used in the derivation of the formulas in this article unless otherwise mentioned.

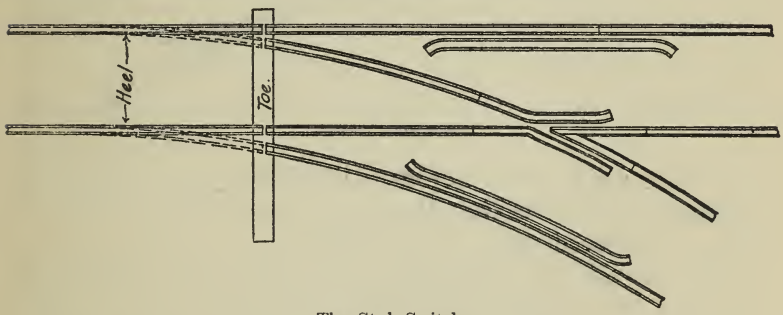
Frogs are designated by numbers from 4 to 24, half numbers being sometimes used between 4 and 12. For crotch frogs and for narrow gage work they sometimes run down to number 2. The most common numbers are 6, 7 and 10.

The actual frog point is situated a certain distance back of the theoretical frog point, this distance being equal to the width of the frog point, times the frog number. The point is usually one half inch wide.

In locating a turnout, whenever possible the *frog number should be chosen first*, for if a curve of a certain degree is chosen and this does not conform to the degree of a regular frog number, a special frog will be necessary.

THE SWITCH.

There are three common kinds of switches, the stub switch, the split switch and the patent form of switch.



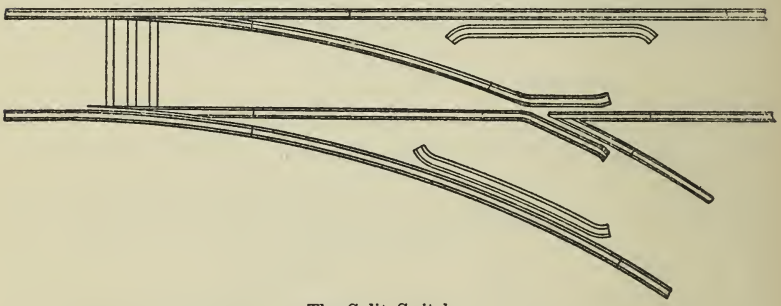
The Stub Switch.

The Stub Switch.—The stub switch is seldom used at the present time on main track. With the stub switch the turnout curve is considered a simple curve from the heel of the switch to the frog point. The switch rails (See the figure) are common to both the main track and the turnout curve. The switch rails are long enough to allow them to be

spiked down for a certain distance back of the heel, and thus when they are set for the turnout, they will be bent practically into the arc of a circle. There must be clearance enough between the rails of the turnout and main track at the toe of the switch to allow the wheels of the train to pass. The main rails and the lead rails are kept at the proper distance apart by use of a device called a head chair.

The two principal objections to the stub switch are, first, the danger of derailment, and second, the difficulty of keeping the proper longitudinal spacing between the switch rails and the rails of the main track and turnout.

Should a train on the main track trail through a stub switch which was set for the side track, it would surely be derailed.



The Split Switch.

With the split switch however, it would many times pass through safely, breaking the connecting rods, provided of course the speed were not too great.

Even though the stub switch is not used to any great extent on main track at the present time, nevertheless the conclusions reached concerning the formulas for lead, etc. for a turnout from a curved main track and those from a straight track when a stub switch is used, are the same as when a split switch is used and they are more easily derived.

The Split Switch.—Where the split switch is used, the outer rail of the main track and the inner rail of the turnout

are continuous. (See the figure). The switch rails make an abrupt angle with the main track.

Patented Switches.—Several different forms of patented frogs and switches are in the market, their object being for the most part to give a continuous main track. The wheels of the train are raised enough to enable the flanges of the wheels to clear the ball of the main rail. They are used in places where the side track is in service but a few times a day. Among this form of switch may be mentioned the Wharton, the Price, the MacPherson and the Coughlin. For details of these switches the reader is referred to the catalogues of the different companies. The mathematics of this form of switch does not differ materially from that of the split switch.

THE LEAD RAILS.

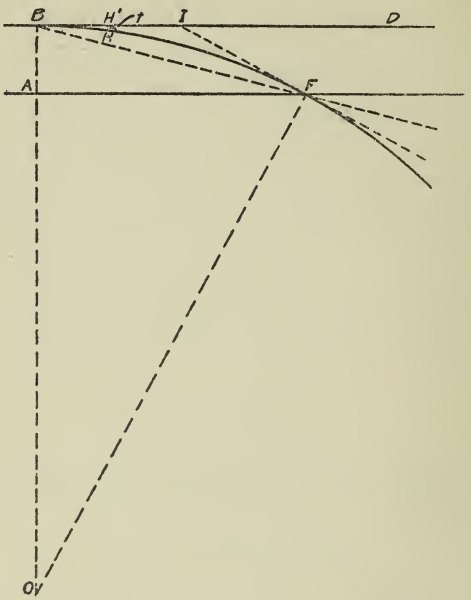
The lead rails connect the switch rails and the frog. The *lead* is the distance from the switch point to the frog point, measured along the main track. There are four common kinds of leads: a, the theoretical lead; b, the stub lead; c, the split lead; and, d, the crotch lead. Exact formulas for each of these leads will be derived, first for a straight main track, and then for a curved main track and finally certain practical conclusions will be reached regarding the latter.

a. **The Theoretical Lead, Main Track Straight.**—When a stub switch is used, the turnout is considered a *simple curve* from the *heel* of the *switch* to the theoretical frog point. Two cases may arise as follows.

Case 1. *To find the theoretical lead in terms of the frog number, N, and the gage, g. Also to find the radius of the center line of the turnout.*

In the figure let the distance HH′ be the throw of the switch and be denoted by t. O is the center of the curve and FI represents the line of the frog produced backward

to meet the main rail. The curve BHF is considered a simple curve. The angle DIF = F = the frog angle.



Now IBF = IFB = $\frac{1}{2}$F. Then in the triangle BFA, the theoretical lead, $s = AB \cot \frac{1}{2}F = g \cot \frac{1}{2}F$. Whence $s = 2Ng$. (3)

Also in the triangle AFO, $\overline{FO}^2 = \overline{AO}^2 + \overline{AF}^2$,

$$\text{or } \left(R + \frac{g}{2}\right)^2 - \left(R - \frac{g}{2}\right)^2 = s^2$$

Whence by expanding and collecting terms, $s = \sqrt{2Rg}$. (4)

By substituting for s its value $2Ng$, we get $2Ng = \sqrt{2Rg}$, from which, $R = 2N^2 g$. (5)

Considering the curve a parabola, and calling the length of the switch rail l, we have $l^2 : s^2 :: t : g$, or $l^2 = \frac{s^2 t}{g} = 4N^2 g t$, from which $l = 2N\sqrt{g t}$. (6)

Case 2. *To find the theoretical lead, s, and the radius of the center line of the curve, R, in terms of the frog angle, F, and the gage, g.*

From the same figure,

$$BA = OF \text{ vers } AOF, \text{ or } g = \left(R + \frac{g}{2}\right) \text{ vers } F,$$

$$\text{whence } R = \frac{g}{\text{vers } F} - \frac{g}{2} \tag{7}$$

$$\text{Also } AF = OF \sin F, \text{ or } s = \left(R + \frac{g}{2}\right) \sin F. \tag{8}$$

Formulas 3 or 4 and 5 are more commonly used than 7 or 8 because they do not require tables containing the functions of F.

Approximate formula for degree of curve. The approximate degree of curve of the stub switch may be found by substituting $\frac{5730}{D}$ for R in equation 5,

whence $\frac{5730}{D} = 2N^2 g$, or $D = \frac{5730}{2N^2 g} = \frac{608}{N^2}$ for gage of 4 feet $8\frac{1}{2}$ inches.

b. **The Stub Lead.**—The stub lead is the distance (measured along the main track) from the point of the stub switch to the frog point, considering the curve a simple curve. The stub lead, *s. l.*, is found by subtracting the length of the switch rail as found by equation 6, from the theoretical lead given by equation 3.

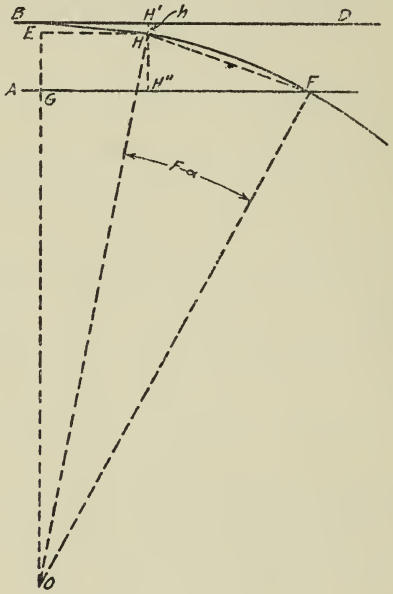
Whence $s.\ l. = 2Ng - 2N\sqrt{gt} = 2N\ (g - \sqrt{gt})$. (9)

A table might be arranged giving values of $g - \sqrt{gt}$ for gages of 3 feet, 4 feet $8\frac{1}{2}$ inches, and 4 feet 9 inches.

c. **The Split Lead, Main Track Straight.**—With the split switch, an abrupt angle is made with the main track. The rails of the frog are seldom curved in practice at the present

time, except for the sharp curves of street railways. Two cases may arise.

Case 1. *To find the split lead, S, and the radius of the lead rails, R, having given the distance h, gage to gage at the heel of the switch, the length of the switch rail, l, and the frog angle, F, the switch rail being considered straight, and the frog rail curved.*



In the figure, HE is drawn perpendicular to EO to meet OE drawn perpendicular to BD. Then the angle HBH′ = HOE = the switch angle = a.

Now sin $a = \frac{h}{l}$

Angle HFH″ = F − ½ (F − a) = ½ (F + a).
Then H″F = H″H cot ½ (F + a), = $(g-h)$ cot ½ (F + a).
Whence S = AH″ + H″F = $l + (g-h)$ cot ½ (F + a) (10)

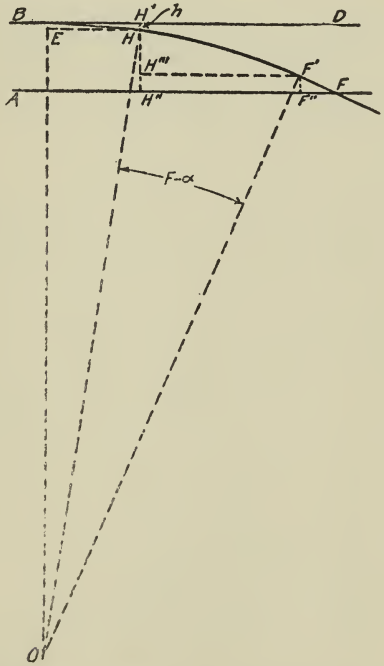
In the triangle HFH″, $FH = \frac{HH''}{\sin HFH''} = \frac{g-h}{\sin \frac{1}{2}(F+\alpha)}$

and $OF = R + \frac{1}{2}g = \frac{FH}{2 \sin \frac{1}{2}(F-\alpha)}$

whence $R + \frac{g}{2} = \frac{g-h}{2 \sin \frac{1}{2}(F+\alpha) \sin \frac{1}{2}(F-\alpha)}$

or $$R = \frac{g-h}{\cos \alpha - \cos F} - \frac{g}{2} \qquad (11)$$

Case 2. *To find the split lead and the radius of the center line, when the frog rail and switch are both considered straight.*



In the figure let the length of the frog FF′, from the point to the toe be designated by *f*.

Then the lead, $S = FF'' + F'H''' + l$.

But $FF'' = f \cos F$, and

$F'H''' \cot \frac{1}{2} HF' H''' = (g - h - f \sin F) \cot \frac{1}{2} (F + a)$.

Therefore $S = l + f \cos F + (g - h - f \sin F) \cot \frac{1}{2} (F + a.)$ (12)

Also $HF' = \frac{HH'''}{\sin HF'H'''} = \frac{g - h - f \sin F}{\sin \frac{1}{2} (F + a)}$ and

$$OH = R + \frac{g}{2} = \frac{HF'}{2 \sin \frac{1}{2} (F - a)} = \frac{g - h - f \sin F}{2 \sin \frac{1}{2} (F - a) \sin \frac{1}{2} (F + a)}$$

$$\text{or } R = \frac{g - h - f \sin F}{\cos a - \cos F} - \frac{g}{2} \qquad (13)$$

Approximate formula for length of lead of a split switch. If the length of the switch rail of the split switch is added to the stub lead as given by equation 9, it will give an approximate value for the split lead.

$$\text{Or } S = 2N (g - \sqrt{gt}) + l. \quad \text{Approx.} \qquad (14)$$

The leads of most roads are computed according to formula 10 of Case 1, except that this distance should be increased by the product of the width of the frog point by the frog number. Unfortunately at the present time there seems to be but little uniformity in the selection of the distances *h*, *f*, and *l*. The distance *h*, depends upon the weight of the rail which is used and the form of angle splice. There should be room enough at the heel of the switch for the insertion of a spike between the angle splice and the base of the continuous rail. This is also a consideration in fixing the length of the frog rails; the larger the number of the frog the greater should be its length. Some roads however use a uniform length for nearly all frog numbers. On account of these differences in practice, leads computed according to the standards of one road would not be exactly true for another and it is mainly for this reason that tables of split leads are not given in existing field books.

Again, slight changes in the length of the lead may have no bad effect on riding but will many times give a better tie spacing or less cutting of rails.

It might be shown by numerical examples that the theoretical lead for a certain frog number is longer than any of the other leads. Then would follow in order the lead with straight frog rail, the lead with straight switch rail, and finally the lead with both switch and frog rails straight.

Comparison of the curves of the theoretical and the split leads. If the same curve were used with the split switch as with the stub switch of the same frog number, the lead in the former would be the shorter, since the switch rail in the split switch is a *tangent* to the curve while with the stub switch it is part of the curve. The curve of the split switch is usually sharper than that of the stub switch, the length of the switch rail and the distance gage to gage at heel of switch being chosen first and the lead rail curve made tangent to them.

d. **The Crotch Lead, Straight Main Track.**—Where two turnouts diverge from the main track, three frogs are necessary. Only the simpler cases will be taken on account of lack of space.

To find the crotch lead in terms of lead of the main frog. In the figure F and F′ are taken equal. Let the distances BC′ and BF be denoted by s_c and s. Then considering the curve a parabola (strictly a simple curve)

$$s_c^2 : s^2 :: \frac{g}{2} : g \text{ or}$$

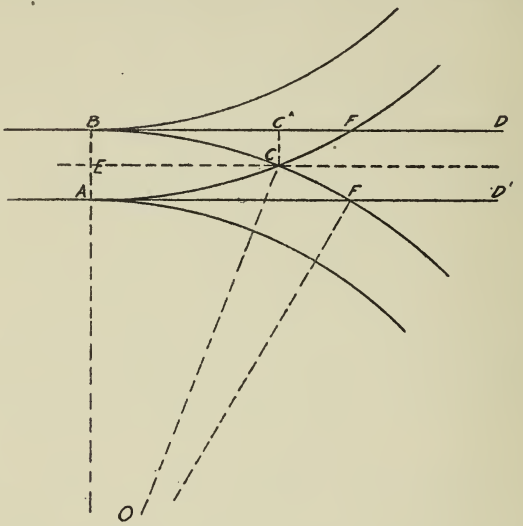
$$s_c = \frac{s}{\sqrt{2}} = .707\ s \qquad (15)$$

or expressed in words, the crotch lead is .707 times the theoretical lead.

The distance FC′ would remain practically the same if split switches were used instead of stub switches, and the

crotch lead would then be equal to the split lead for the main frog minus .3 of the theoretical lead for the same number.

To find the crotch frog. Two cases may arise as follows:



Case 1. To find the crotch frog, having given the radius of the curve R, and the gage g.

$$\text{In the figure, vers AOC} = \frac{CC'}{OC}$$

$$\text{or vers } \tfrac{1}{2}C = \frac{g}{2\left(R+\frac{g}{2}\right)} \qquad (16)$$

Case 2. To find the number of the crotch frog, N_c, having given the number of the main frog, N.

$$\text{From the figure, cot AOC} = \cot \tfrac{1}{2}C = \frac{R}{s_c}$$

$$\text{but since cot } \tfrac{1}{2}F = 2N, \text{ cot } \tfrac{1}{2}C = 2N_c.$$

$$\text{Then } s_c = \frac{R}{2N_c} = \frac{N^2 g}{N_c} \qquad (17)$$

$$\text{Also } s_c^2 = \overline{OC}^2 - \overline{OE}^2 = \left(R + \frac{g}{2}\right)^2 - R^2 = Rg + \frac{g^2}{4} = 2N^2 g^2 + \frac{g^2}{4}$$

$$\text{or neglecting } \frac{g^2}{4}, \text{ then } s_c = g\sqrt{2N^2} \qquad (18)$$

Equating the two values of s_c given in equations 17 and 18, there results $N_c = \frac{N}{\sqrt{2}} = .707N.$ (19)

The next article will treat of turnouts from curved tracks; the guard rails; the track beyond the frog, with the methods of staking it out in the field; slip switches; crossings and structural details.

SWITCHES AND TURNOUTS.*

By Howard Chapin Ives, Assistant Professor of Railroad Engineering.

In the last article formulas were derived for the different kinds of leads where the main track was straight. Formulas will now be derived when the main track is curved.

THE LEAD RAILS CONTINUED.

The lettering and designation of the leads will be the same as that already given.

a. **The Theoretical Lead, Main Track Curved.**—Three cases may arise as follows: first, where the turnout is on the inside of the main track; second, where the turnout is on the *outside* of the main track, with the center of the turnout on the *inside* of the main track; and third, where the turnout is on the *outside* of the main track, but with the center of the turnout on the *outside* of the main track.

Case 1. *To find the radius and lead of a turnout from the inside of a curved main track, having given the radius of the main track, R', the frog angle, F, the frog number, N, and the gage, g.* Let BD be the outer rail of the main track, and BF that of the turnout. C is the center of the main track, and O is the center of the turnout. Draw BF and AF. Designate the radius of the turnout by R''; the theoretical lead, AF, by s_t; the angle BCF by C, and the angle BOF by O.

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In the triangle BFC, $CB = R' + \frac{g}{2}$

$$CF = R' - \frac{g}{2}$$

$$C = 180° - (BFC + FBC)$$

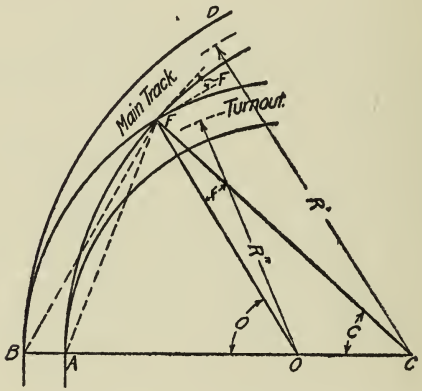
and $BFC - FBC = BFC - BFO = F$.

Now, $\tan \frac{1}{2}(BFC + FBC) : \tan \frac{1}{2}(BFC - FBC) :: (BC + CF) : (BC - CF)$

or $\cot \frac{1}{2} C : \tan \frac{1}{2} F :: 2R' : g$

and $\tan \frac{1}{2} C : \cot \frac{1}{2} F :: g : 2R'$, from which since $\cot \frac{1}{2} F = 2N$,

$$\tan \frac{1}{2} C = \frac{Ng}{R'} \qquad (20)$$



Then solving the triangle AOF in a similar manner, the equation $\tan \frac{1}{2}(F + C) = \frac{Ng}{R''}$ is obtained from which

$$R'' = \frac{Ng}{\tan \frac{1}{2}(F + C)} \qquad (21)$$

The chord AF = the theoretical lead =

$$s_t = 2AC \sin \tfrac{1}{2}C = 2\left(R' - \frac{g}{2}\right)\sin \tfrac{1}{2} C. \qquad (22)$$

Case 2. *To find the radius and theoretical lead of a turnout from the outside of a curved main track, when the center of*

the turnout curve lies on the inside of the main track, having given the radius of the main track, R′, the frog angle, F, the frog number N, and the gage g.

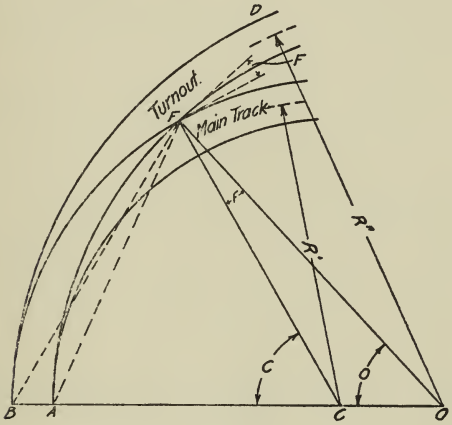
The method of procedure is the same as in the first case, the letters O and C being interchanged on the sketch.

In the triangle ACF, $FC = R' + \frac{g}{2}$

$$AC = R' - \frac{g}{2}$$

$$FAC + AFC = 180° - C$$

$$FAC - AFC = AFO - AFC = F$$



And by the tangent formula

$\tan \frac{1}{2}(FAC + AFC) : \tan \frac{1}{2}(FAC - AFC) :: FC + AC : FC - AC$

$\therefore \cot \frac{1}{2} C : \tan \frac{1}{2} F :: 2R' : g$, from which $\tan \frac{1}{2} C = \frac{Ng}{R'}$ (23)

Solve the triangle BFO in a similar manner and the following equation will be obtained $R'' = \frac{Ng}{\tan \frac{1}{2}(C - F)}$ (24)

The theoretical lead $= BF = 2\,BC \sin \frac{1}{2} C =$

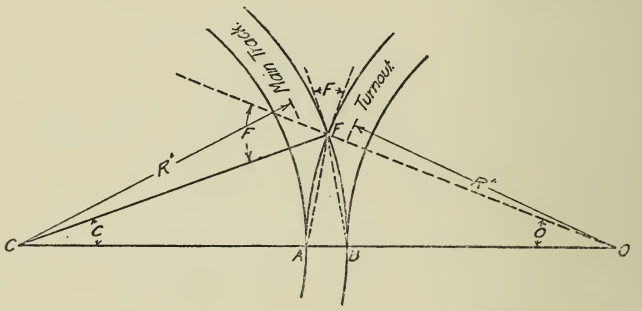
$$s_t = 2\left(R' + \frac{g}{2}\right) \sin \tfrac{1}{2} C. \qquad (25)$$

Case 3. *To find the radius and theoretical lead of a turnout from the outside of a curved main track when the center of the turnout curve lies on the outside of the main track, having given the radius of the main track, R′, the frog angle, F, the frog number, N, and the gage, g.*

AF is the outer rail of the turnout, and BF that of the main track. Solve the triangle FCA by the tangent formula, which gives $\tan \frac{1}{2}(CAF+CFA) : \tan \frac{1}{2}(CAF-CFA) :: FC+AC : FC-AC$, but $CAF+CFA=180°-C$ and

$$CAF-CFA=180°-OAF-(180°-OFA-F)=F, \text{ and}$$

$$CF=R'+\frac{g}{2},\quad CA=R'-\frac{g}{2}$$



Making these substitutions, and remembering that $\cot \frac{1}{2} F = 2N$, there results

$$\tan \tfrac{1}{2} C=\frac{Ng}{R'} \qquad (26)$$

In a similar manner solve the triangle BOF, where angle $BOF=F-C$, and obtain

$$\tan \tfrac{1}{2}(F-C)=\frac{Ng}{R''} \text{ or } R''=\frac{Ng}{\tan \frac{1}{2}(F-C)} \qquad (27)$$

Also the chord BF = the theoretical lead =

$$s_t=2\left(R'+\frac{g}{2}\right)\sin \tfrac{1}{2} C. \qquad (28)$$

Remarks. If the student will bear the following things in mind the above proofs will be easily remembered. In all three cases, the triangle to be solved first is the one containing the line from the center of the main track to the frog point, the other side of the triangle differing from this line by the quantity g, and then the triangle from the center of the turnout curve should be solved, the sides of which also differ by the quantity g.

Approximate Formulas and Practical Conclusions.—Consider equation 22 of case 1.

Neglecting $\frac{g}{2}$ and replacing $\sin \frac{1}{2} C$ by $\tan \frac{1}{2} C$,

and since $\tan \frac{1}{2} C = \frac{Ng}{R'}$ from equation 20

we get $s_t = 2R' \tan \frac{1}{2} C = 2 Ng.$ (29)

Equation 29 is the same as equation 3, and the same results may be obtained from equations 25 and 28. Or expressed in words:

With a certain frog number, the theoretical lead of a turnout from a curved main track is practically the same as it is from a straight main track with the same frog number.

It will now be shown that a simple relation exists between the degrees of the different curves.

Consider case 1, and equations 5, 20 and 21 which are

$$R = 2N^2 g = \frac{Ng}{\tan \frac{1}{2} F} \quad (5)$$

$$R' = \frac{Ng}{\tan \frac{1}{2} C} \quad (20)$$

$$R'' = \frac{Ng}{\tan \frac{1}{2} (F+C)} \quad (21)$$

Where R is the radius of the center of the turnout from a straight track, with frog number N.

$$\text{Whence } R : R' : R'' :: \frac{5730}{D} : \frac{5730}{D'} : \frac{5730}{D''} ::$$

$$\frac{Ng}{\tan \frac{1}{2} F} : \frac{Ng}{\tan \frac{1}{2} C} : \frac{Ng}{\tan \frac{1}{2} (F+C)}$$

$$\text{or } D : D' : D'' :: \tan \tfrac{1}{2} F : \tan \tfrac{1}{2} C : \tan \tfrac{1}{2} (F+C)$$

$$D : D' : D'' :: F : C : (F+C)$$

$$D+D' : D'' :: F+C : F+C$$

$$\text{From which } D'' = D+D' \quad \text{(approx.)} \qquad (30)$$

Or expressed in words: *with a certain frog number the degree of curve of a turnout from the inside of a curved main track is equal to the degree of curve of the main track plus the degree of curve of the turnout for a frog of the same number from a straight main track.*

Cases 2 *and* 3. In case 2, it may be proved that the degree of curve of the turnout from the *outside* of a curved main track, with the center on the *inside* of the main track, is equal to the difference between the degrees of the main track and the degree of a frog from a straight track of the same number, or

$$D'' = D' - D \qquad (31)$$

And in case 3, when the turnout is *outside* of a curved main track with the center *outside* the main track, the degree of curve of the turnout is equal to the difference between the degree of curve of the frog from a straight main track and the degree of the main track, or

$$D'' = D - D'. \qquad (32)$$

Note. It is suggested that the student solve a practical example by use of the equations in one of the three cases above and then by use of the approximate equations just deduced see the variation and effect of the approximations.

Formulas 20–28 are seldom used in actual railroad work but are given here in order to compare the exact equations with the approximate ones.

b. **The Stub Lead, Main Track Curved.**—The stub lead might be found by subtracting the length of the switch rail from the leads as given by the exact formulas, 22, 25 and 28, but the approximate formula is usually used which would be the same as equation 9.

c. **The Split Lead, Main Track Curved.**—Exact formulas might be deduced for the split lead when the main track is curved for the three cases already given, and approximate formulas and conclusions could then be reached similar to those for the theoretical lead. In other words the same split lead is used on a curved main track as on a straight main track, and the degrees of curve of the turnout are found in a similar manner.

THE RAILS BEYOND THE FROG.

A turnout will usually assume one of the following forms beyond the frog point.

A. It may be part of a cross over between parallel tracks, the tracks being either straight or curved.

B. It may be straight beyond the frog point, or the curve may be continued as a simple or compound curve to any desired point, or there may be a combination of curves and tangents.

C. It may extend to a parallel side track, the tracks being either straight or curved.

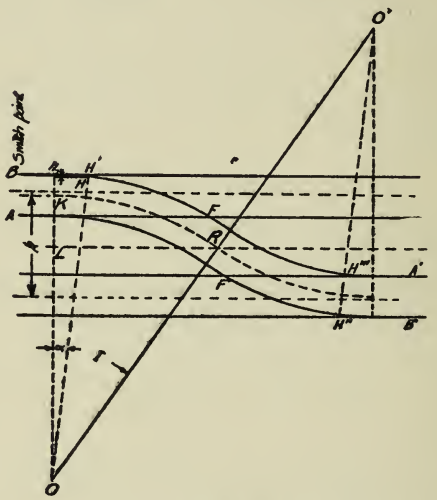
A. Three cases may arise: first, where the tracks are straight and the turnout is in the form of a reversed curve; second, where the tracks are straight but where a tangent comes between the two curves; and third, where the tracks are curved and the crossover is in the form of a reversed curve.

Case 1. *Having given the perpendicular distance, between parallel tracks,p, and the common radius of the reversed curve, R, to find the central angle of the curve.*

The point of reverse curve will be on the center line between tracks. Then from the figure the distance between the

outer rail of the turnout curve produced backward through the angle a and the gage line of the main track will be $h-\left(R+\frac{g}{2}\right)$ vers a and the center line of the turnout will be offset by the same amount.

$$\text{And vers } (I+a)=\frac{KL}{OR}=\frac{\frac{p}{2}-\left[h-\left(R+\frac{g}{2}\right)\text{vers } a\right]}{R} \qquad (33)$$



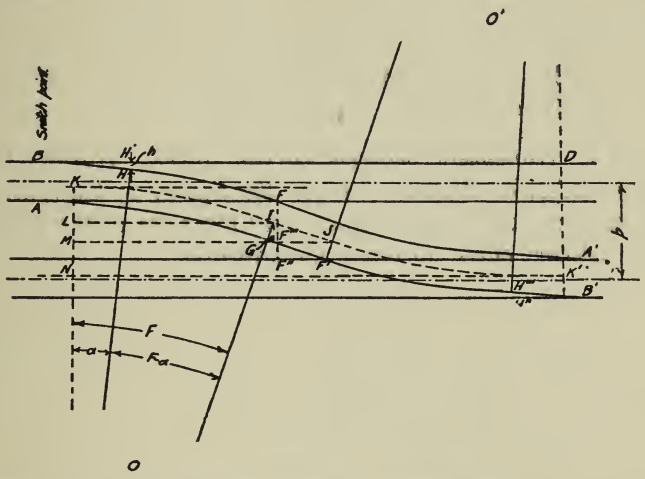
The lengths of the curves may then be found knowing their central angles and degrees.

In order to avoid the use of a special frog, the number of frog, N, is usually chosen first, and then R is computed from equation 11.

Case 2. *Having given the perpendicular distance between parallel tracks, p, the frog number, N, with the radius corresponding, (from equation* 11) *to find the length, d, of the tangent between the two curves of equal radii.*

The frog rails will be considered curved and the switch rails straight as in the first case. K and K′ are the centers

of the turnout curves produced backward through the switch angle a. Then $IG=IJ \sin IJG=d \sin F$. The distance KN is less than p by the amount $2\left[h-\left(R+\frac{g}{2}\right)\text{vers } a\right]$ (See Case 1.)



Then $IG=KN-KL-NM=p-2\left[h-\left(R+\frac{g}{2}\right)\text{ vers } a\right]-$

$$R \text{ vers } F-R \text{ vers } F.$$

Equating the two values of IG and solving for d, we get

$$d=\frac{p-2\left[h-\left(R-\frac{g}{2}\right)\text{vers } a\right]}{\sin F.}-\frac{2R \text{ vers } F}{\sin F} \qquad (34)$$

Approximate distance from frog point to frog point measured along the main rail. The distance F″ F‴ is approximately equal to $p-2g$. Then using the third method for frog number as given in the first article we get

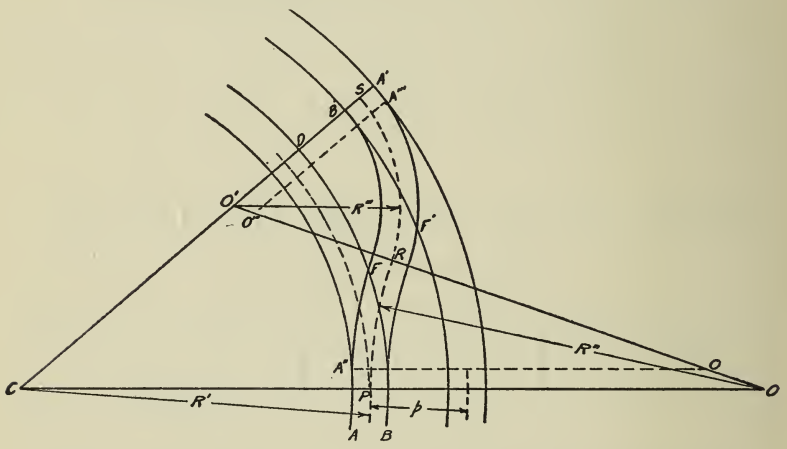
$$F' F''=(p-2g) N. \qquad (35)$$

Remark. Case 1 as given above is not used except where p is large and a saving of room is desired. The method

given in case 2 is recommended since the frog from the point to the heel is actually a tangent and the formulas therefore conform to practical railroad work.

Note. Some roads consider the frog from point to toe straight. The lead in this case would be computed from equation 12 and the radius of the lead rails from equation 13. An excellent table of cross-overs is given in a letter by Mr. J. H. Milburn, of the Baltimore and Ohio Railroad in the *Engineering News*, July 13, 1905, page 42.

Case 3. *Crossovers between curved tracks. Having given the perpendicular distance between the tracks, p, the radius of the center line of the inner track, and the radii of the two arcs of the reversed curve, to locate the crossover.*



The problem will first be solved for a stub switch and then the modifications will be given when a split switch is used. Ordinarily in practice the frog numbers are first chosen and the radii computed from equations 27 and 21 or by the approximate formulas 32 and 30. The problem will be solved when the central angles of the two arcs are found, since their degrees will be known and their lengths may be

computed. In the figure, BD represents the outer rail of the inner track, and PRS the center line of the cross-over.

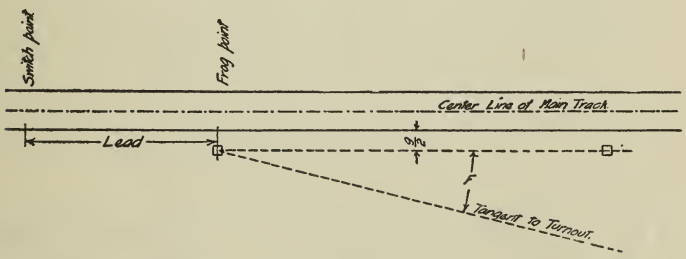
Solve the triangle COO′ for the angles at C, O and O′, having given the three sides, CO=R′+R″; CO′=R′+p−R‴; and OO′=R″+R‴.

Then the angle A′O′R=C+O, and the lengths of the two arcs PR and RS may be found knowing their central angles and their degrees (from the radii).

Split Switches. When split switches are used the values of R″ and R‴ will be smaller than with stub switches, and the method of finding them has already been given in the other article. The switch points will be at some points such as A″ and A‴. The central angles A″O″R and A‴O‴R will be equal to those found for the stub switch, but in this case the central angles of each *arc* will be diminished by the switch angle.

Approximate Method. The lengths of the different parts may be found considering the tracks straight as in Case 1, and the lengths thus found used in this case. If p is small as compared with R′, the degree of the outer track need not be found before finding R‴, but its degree may be considered the same as for the inner track.

B. No special formulas need be derived in this case. After the frog point is located, a tangent to the turnout



curve is found as shown in the accompanying sketch, and from this tangent the work proceeds as in any straight line or curve work. The combination of curves and tangents

will depend of course on the number and location of the frog, and the point which is to be reached.

C. **When the Parallel Tracks are Straight.**—*Given the radius of the first curve, R, the perpendicular distance between tracks, p, and the frog angle F, to find the radius of the second curve, R′, to connect the parallel tracks by a reversed curve, the point of reversed curve being taken at the frog point.*

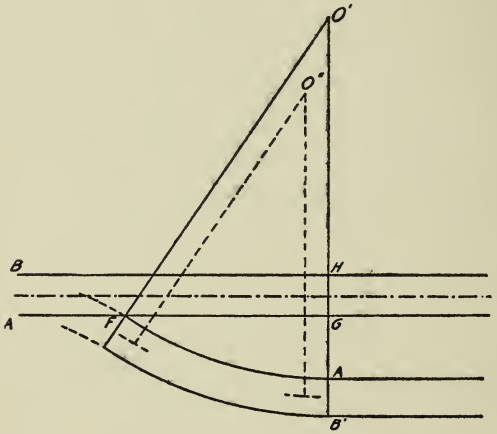
The angle $FO'A = F$.

$$GA = GB' - AB' = p - g$$

$$GA = FO' \text{ vers } FO'A = \left(R' - \frac{g}{2}\right) \text{ vers } F.$$

Combining these equations and solving we get

$$R' = \frac{p-g}{\text{vers } F} + \frac{g}{2} \tag{36}$$



It should be here noted that this solution does not depend upon the kind of switch used. The position of the switch point depends of course upon the kind of lead adopted.

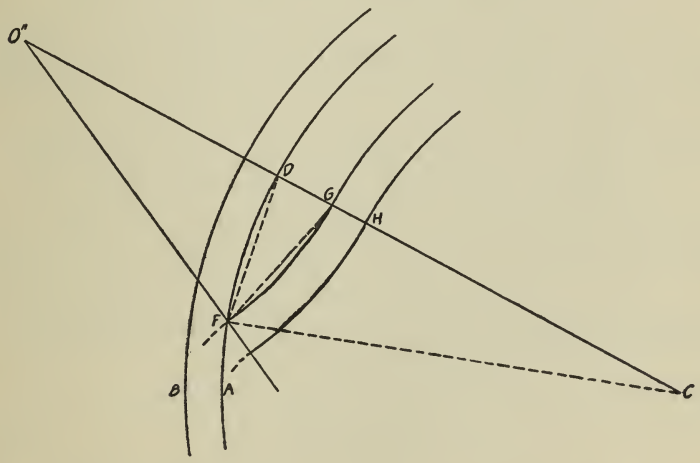
Straight rail beyond the frog point. If the frog from the point to the heel is considered straight, or if there is a piece

of straight track beyond the frog point of length f, the radius of the second curve must be slightly reduced. The position of the center of the new curve is shown at O'' and the dotted lines represent the new radii. Equation 36 then becomes

$$R' = \frac{p - g - f \sin F}{\text{vers } F} + \frac{g}{2} \qquad (37)$$

When the Parallel Tracks are Curved.—Three cases may arise as follows:—1. Where the siding is inside the main track. 2. Where the siding is outside the main track with the center of the turnout and connecting curve inside the main track. 3. Where the siding is outside the main track, with the center of the turnout curve outside the main track but with the center of the connecting curve inside the main track.

In all of these cases the leads, radii and degrees of the turnout curves will depend upon the form of the center line of turnout, and formulas have already been deduced for them.



In each case the problem will be solved after the radius and length of the connecting curve are found.

1. *Having given the radial distance between the parallel tracks, p, the radius of the main track, R′, the frog angle, F, and the gage, g, to find the radius and length of the connecting curve.*

Let AFD represent the inner rail of the main track, and BFG that of the turnout and connecting curve.

$$DH=p.$$

Then in the triangle CFG,

$$FC=R'-\frac{g}{2}$$

$$GC=R'-p+\frac{g}{2}$$

$$FGC+GFC=180°-C$$

$$FGC-GFC=F, \text{ since } O''FG = O''GF$$

Then $\tan \frac{1}{2}(FGC+GFC) : \tan \frac{1}{2}(FGC-GFC) :: FC+GC : FC-GC$

and $\cot \frac{1}{2} C : \tan \frac{1}{2} F :: 2R'-p : p-g$

or $\tan \frac{1}{2} C : \cot \frac{1}{2} F :: p-g : 2R'-p$

from which $$\tan \tfrac{1}{2} C=\frac{(p-g)\,N}{R'-\frac{p}{2}} \qquad (38)$$

Then solve the triangle O″FD, where angle $O''=F-C$,

$$O''DF+O''FD=180°-O''=180°-(F-C)$$

$$O''F=R'''-\frac{g}{2}; \quad O''D=R'''+\frac{g}{2}-p$$

$$O''DF-O''FD=F$$

and $\tan \frac{1}{2}(O''DF+O''FD) : \tan \frac{1}{2}(O''DF-O''FD) :: O''F+O''D : O''F-O''D$

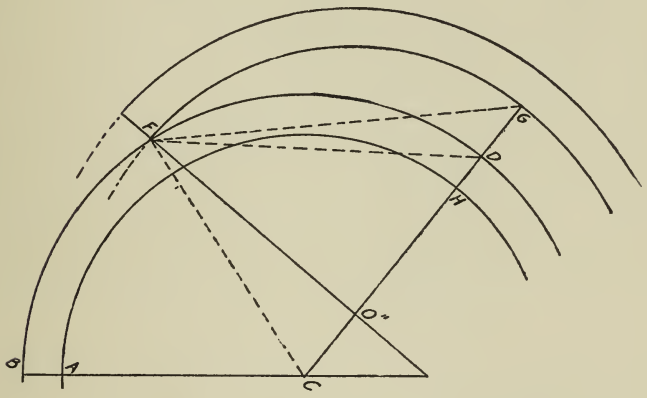
from which in a similar way to that given above

$$R'''=\frac{(p-g)\,N}{\tan \frac{1}{2}(F-C)}+\frac{p}{2} \qquad (39)$$

$$\text{The length of the connecting curve}=\frac{100\,(F-C)}{D'''} \qquad (40)$$

2. *When the siding is outside the main track but with the center of both turnout and connecting curve inside the main track.* Solve the triangle FCG in an entirely similar manner to that given in case 1 and we get

$$\tan \tfrac{1}{2} C = \frac{(p-g)\ N}{\left(R' + \frac{p}{2}\right)} \tag{41}$$



and from the triangle O''FD, $R''' = \frac{(p-g)\ N}{\tan \frac{1}{2} (F+C)} + \frac{p}{2}$ (42)

The length of the curve $= \frac{100\ (F+C)}{D'''}$ (43)

3. *When the siding is outside the main track with the center of the turnout curve outside the main track but with the center of the connecting curve inside the main track.*

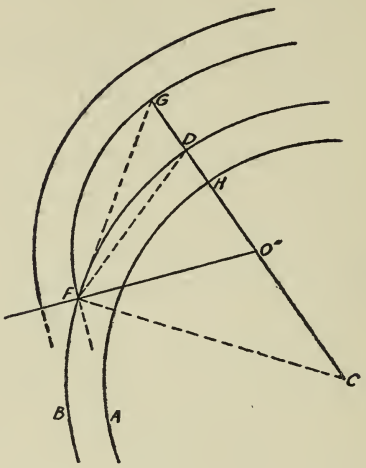
Solve the triangle FGC as in the preceding case and obtain

$$\tan \tfrac{1}{2} C = \frac{(p-g)\ N}{R' + \frac{p}{2}} \tag{44}$$

and then solve the triangle FDO'' and obtain

$$R''' = \frac{(p-g)\ N}{\tan \frac{1}{2} (F+C)} + \frac{p}{2} \tag{45}$$

$$\text{The length of the curve} = \frac{100\,(F+C)}{D'''} \qquad (46)$$



Approximate method. The degree of the turnout curve in the different cases might be found in the manner already explained, that is, by adding or subtracting D′ (the degree of the main track) to or from D″, the degree of the turnout curve. If the turnout were computed as if straight and the degree of the connecting curve D‴ obtained, then the degree of the curve with a curved crossover would be found by adding or subtracting D″ to or from this value. The lead of the turnout and the length of the connecting curve would be practically the same as if a straight track were used.

The above statements are based on demonstrations similar to that given for finding equation 30. It can readily be seen that the error in the connecting curve will be greater by these approximations than in the turnout curve on account of the fact that p is usually at least twice and a half as large as g.

THE GUARD RAILS.

Guard rails are placed opposite the frog point in order to keep the wheels in line and to prevent them battering the point or getting on the wrong side of the point.

Practice varies with regard to the shape and dimensions of the guard rails. As a rule they are about 15 feet long and straight in the middle for a distance of 6 to 11 feet and then curved at each end. Some roads make them curved throughout, the radius of the curve being comparatively large. They are held in place by rail braces and the proper flangeway between the main rail is secured by the use of fillers or clamps. The flangeway is usually one and three quarters inches and with some weights of rails this will necessitate a planing of the base of the rail near the center. Usually the guard rail is not placed symmetrically with respect to the frog point but the length beyond the point is from one to two feet more than that back of the point.

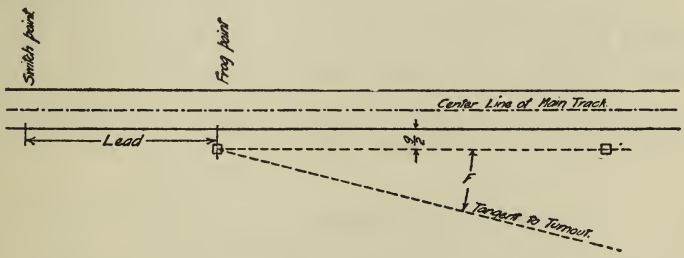
SWITCHES AND TURNOUTS.*

By Howard Chapin Ives, Assistant Professor of Railroad Engineering.

METHODS OF STAKING OUT A TURNOUT.

There are three common methods for staking out a turnout from an existing track.

First: **By Eye.** *When the main track is straight.* Decide upon the position of the frog point, and drive two stakes at distances of one half the gage from the near rail. Set up at the first stake and with an angle laid off on the plate equal to the frog angle (and in the proper direction) find the tangent to the turnout curve. The curve beyond the frog point is located the same way as any curve.



After computing the lead for the particular switch and frog, the switch point is found, as shown in the sketch. *The lead rails are then located by the eye of the section foreman.*

When the main track is curved. If the main track is in good alinement the degree of the curve and the location of

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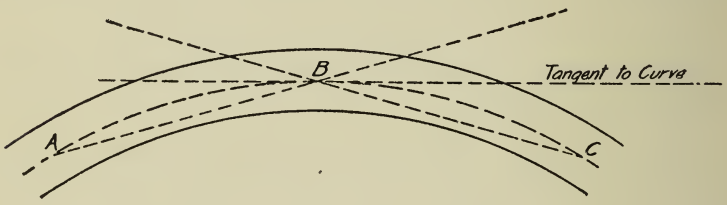
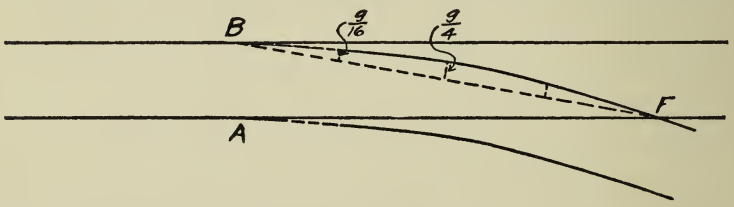
the common tangent may be found as shown in the figure. The distances AB and BC are equal to 100 feet. The deflection angle between the chords is equal to the degree of curve. The common tangent to the curve is found by bisecting the angle between AB produced and BC. The deflection angles for the turnout curve beyond the frog point will depend upon the degree of the turnout curve. The methods of finding the degree of the turnout curve have already been given.



The switch point is found by laying off the lead for the proper switch and frog, and the turnout curve from switch point to frog point is located by the eye of the section foreman as in the case of a straight main track.

Second. *By offsets from the long chord of the curve, a stub switch being used.* Select the frog point F, and lay off the lead FA=2N*g*. The offset from the chord BF at the middle

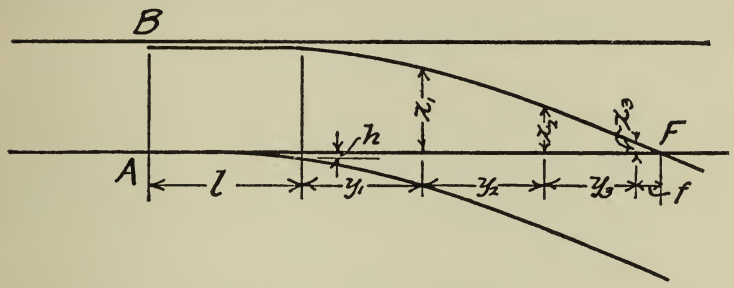


point will be g/4 and that at the quarter point will be g/16.

Third. *When a split switch is used,* the frog and switch points are first located, and the switch rails placed in position, giving the proper offset *h*, at the heel of switch. Points on the lead curve may be found by laying off the distances

y_1, y_2 and y_3, along the main rail and x_1, x_2 and x_3 at right angles to the main rail.

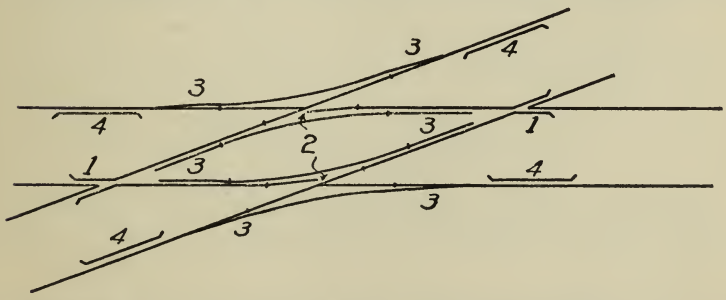
These values may be found either by computation or by plotting at a large scale and measuring the distances. A large number of diagrams are given in a book entitled "Switch Layouts and Curve Easements" published by the Railroad Gazette.



Note. Of the three methods given above, the first is used by most engineers for ordinary work. Where the main track is curved, the approximate formulas as previously deduced are used instead of the exact formulas.

DESIGN OF A DOUBLE SLIP SWITCH CROSSING WITH MOVABLE FROG POINTS.

At a crossing of two tracks, traffic may be switched from



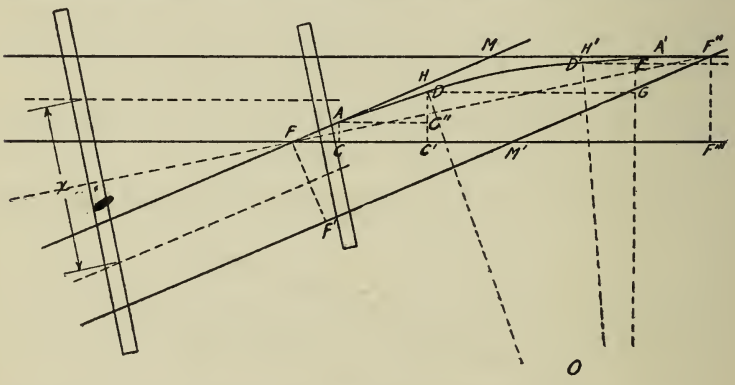
one track to the other by a combination crossing called a slip switch. The switches and lead rails are entirely included

between the main frog points. A great saving of room is gained, but on account of the small distance between main frog points, the angle between the tracks must be slight.

A sketch of a double slip switch is given above, the different parts being designated as follows:—1, Rigid Frog; 2, Movable Frog Points; 3, Switch Points; and, 4, Guard Rails. The central frog points may either be rigid or have movable points. In the latter case the switch rails and movable frog rails must be properly interlocked.

Given Data. Before developing the formulas the following things must be assumed:—the number of the crossing, N, the gage, g, the lengths of switch and movable frog rails, l, the throw of the switch rails, t, the length of the rigid frog, the distance gage to gage at heel of switch, h, and the width of the frog point, P.

In addition to these items, the weight of rail must be considered and also the form of joint (whether supported or



suspended) and the tie spacing. It may be impossible to secure both a uniform tie spacing and all joints exactly centered.

To find the distance from frog point to frog point measured along the bisector of the frog angle. In the figure solve the

triangle F″ FF‴, where F″F‴ $=g$, and angle F″FF‴ $=\frac{1}{2}$F, and we obtain $FF'' = \frac{g}{\sin \frac{1}{2}F}$.

This is the distance between the *theoretical rigid* frog points, and to find the distance between the actual frog points, the distance 2NP (usually =N in inches, the point being one-half inch wide) is added to FF″. To aid in plotting, the distances FM′ and M′F‴ may be found from the triangles FF′M′ and F″M′F‴ by the equations FM′ $=g \diagup \sin F$ and M′F‴ $=g \times \cot F$.

To find the radius of the outer rail of the curve. In the figure A and A′ represent the actual switch points which are equidistant from the theoretical frog points F and F″. The distance FA depends upon the frog number, the tie spacing, form of joint used, the section of rail and form of clip. The center of the curve of the outer rail is at O, and the distances HD and H′D′ are denoted by h. The switch angle HAD $=a$, is found from the equation $\sin a = \frac{h-w}{l}$, where w, is the width of switch point. Then the central angle of the curve DOD′ $=F-2a$, and EG $=F''F'''-H'D'-AC-DC'' = g-h-FA \sin F - l \sin (F-a)$. The distance EG also equals $OE-OG=\left(R+\frac{g}{2}\right)\cos a - \left(R+\frac{g}{2}\right)\cos (F-a)$. Equating these two values of EG and solving for R we obtain

$$R=\frac{g-h-FA \sin F-l \sin (F-a)}{\cos a-\cos (F-a)}-\frac{g}{2}. \qquad (47)$$

The degree of curve of the outer rail may then be found from tables or from the equation $\sin \frac{1}{2}D=\frac{50}{R}$. The length of

of the rail DD′ may be found from the regular formula for length of curve, which in this case becomes $\frac{100\ (F-2a)}{D}$.

Planing of switch rails. The distance HD is determined by the section of the rail and the form of angle splice. This distance should be enough to allow the insertion of a spike between the angle splice and the base of the main rail. The theoretical distance, *d*, from the heel of switch ~~point~~ to the place where the base of the switch rail must be planed is $\frac{h-b-w}{\sin a}$, where *b* = the width of the base of rail. This theoretical distance should be increased slightly.

Planing of movable frog rail. The distance, d′, from the theoretical point M to the point where the base of the movable frog rail must be planed is found from the equation $d'=b \diagup \tan F$. The correctness of these formulas may be seen by making two simple sketches.

Calculation of length and spacing of ties. The ties are to be spaced as nearly uniform as possible and are perpendicular to the line FF″. Usually the ties between the switch points are all of the same length and about twelve feet. Sometimes however every third or fourth tie is longer in order to form a support for the operating rods. The ties from the switch point at A to the last long tie increase uniformly in length the increment of increase being the difference in length of the last long tie and that at the switch point, divided by the number of spaces, the nearest inch being used. The last long tie is usually not longer than 16 ft. 10 in. The spacing of the ties from the point A to the last long one is usually 24 inches center to center, and the distance from the center of the crossing to the last long tie is found from the equation (T−*e*)N, where T is the length of the longest tie, *e*, the length of standard tie for single track, and N, the frog number. The length T, may be changed slightly so as to

give a whole number of inches for the spacing. The two ties at the movable frog points are usually a little further apart than the others. It will usually be necessary to have two ties of fractional inch spacing.

Arrangement of joints. The inner rails of the curve are continuous. Certain joints (such as those at the heel of switch and movable frog rails) are fixed. A careful study must then be made for the lengths of rails and tie spacing in order to give the desired form of joint (suspended or supported.)

Details of the design. The details of the frogs, switch rails, tie bars, slide plates, switch clips, guard rails, etc., may best be studied by use of the standard designs of different railroads or manufacturers. In designing a crossing of this nature, the cost may be materially reduced by adopting as far as possible the standard dimensions of the manufacturers.

THE END.

ERRATA.

In the March number three errors occurred as follows:

A minus sign should be inserted between the two terms of the denominator of equation 11. In eq. 13, "$f - \sin f$" should be "f sin F," and the third line of the same page should be: $F'H''' = HH''' \cot HF'H''' = \text{etc.}$

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